Determining the Correct Crystal Load Capacitance for use with GreenCLK

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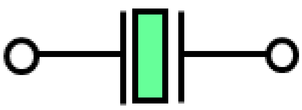
Introduction

Crystals have long been used as stable frequency sources. They are most commonly used as a stand-alone component in conjunction with an IC that provides an oscillator circuit. The crystal and IC must be matched in terms of several parameters.

Crystal Background

A crystal resonator is essentially a piece of quartz with two electrodes plated or deposited on opposing sides. The crystalline structure of quartz provides it with the ability to vibrate when provided with an electrical signal. This phenomenon is known as the piezoelectric effect.

The circuit symbol for a crystal resonator is shown in Figure 1.



R1Figure 1. Quartz crystal schematic symbol

The basic parameters associated with a crystal resonator are:

Co = holder or parallel plate capacitance

C1 = motional capacitance (also called Cm)

L1 = motional inductance (also called Lm)

R1 = motional resistance (also called Rm)

C_L = load capacitance (circuit capacitance)

Sometimes there is confusion on the part of design engineers between R1 and ESR (equivalent series resistance). It should be noted that they are related by Equation 1.

$$R1 = ESR * (1 + \frac{Co}{C_L})^2$$

Equation 1. Relationship between ESR and

The electrically equivalent circuit for a crystal is shown in Figure 2. Co, C1, L1, and R1 represent the crystal. Most crystals are operated in parallel mode. This occurs when the crystal is operated in a circuit that presents a capacitance to the crystal. The crystal is manufactured in such a way that its frequency is tuned to that circuit capacitance.

This can present issues in the final circuit design if the crystal is manufactured for one load capacitance value and the electrical circuit is at a different load capacitance.

For example, if a crystal is designed for a load capacitance of 12 pF, but the circuit it is used in is at 8 pF, then the crystal will operate at a much higher frequency in that circuit. It will most likely be tens of ppm high in frequency which could result in a system failing to operate correctly.

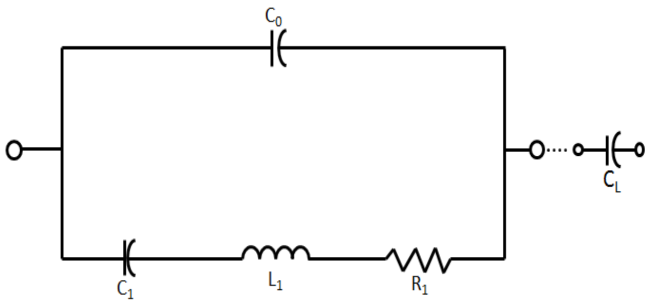


Figure 2. Crystal electrical equivalent model

GreenCLK Solution

In order to determine the exact load capacitance that a circuit is operating at, simple measurements will not suffice. Not only must stray capacitance from the IC be accounted for, but stray capacitance from the PCB layout too. External capacitors also have tolerances that can affect circuit load.

GreenCLK solution is to use a crystal whose parameters have been fully characterized, and then to measure the frequency of this crystal in the end circuit. The difference in frequency will indicate the difference in capacitance between the crystal load and the circuit load. The difference is characterized by Equation 2 where CL1 and CL2 represent the crystal load and circuit load capacitances.

$$Change(ppm) = \frac{-Cm*(C_{L2}-C_{L1})*10^6}{2*(Co+C_{L2})*(Co+C_{L1})}$$

Equation 2. Difference in capacitance between the crystal load and the circuit load

It has been created a simple Excel tool to help with this task. The basic values from the characterized crystal need to be entered in to it as well as the crystal frequency in the customer circuit. The tool will calculate the frequency change in ppm and the subsequent required change in crystal load capacitors on the customer PCB.

Related Files

- GreenCLK Crystal Load Calculation Tool, Excel spreadsheet, v1.0,

References

- Vig, J. R., Quartz Crystal Resonators and Oscillators, Powerpoint presentation, January 2004, v8.5.2.0
- Veeser, M., Common Sense Oscillator Techniques.